"Simulation of Extreme Arctic Cyclones in IPCC AR5 Experiments"

PI: Stephen Vavrus
Nelson Institute Center for Climatic Research
1225 W. Dayton Street
Madison, WI 53706
phone: 608-265-5279, fax: 608-263-4190, email: sjvavrus@wisc.edu

LONG-TERM GOALS

The primary goals of this project are to assess the ability of the current generation of global climate models (GCMs) to simulate extreme Arctic cyclones and identify changes in the characteristics of these storms caused by greenhouse-forced climate change to present.

OBJECTIVES

These goals are being addressed through the following questions. First, how realistically does the widely used CCSM4 GCM simulate the observed characteristics of extreme Arctic cyclones and how sensitive are these events to the horizontal resolution of the model? Second, do other GCMs generate such storms and, if so, are there any common characteristics among models that successfully do so? Third, does the preferred location of these systems and their impacts shift as the cyclogenetic baroclinic zone induced by the sea ice margin migrates poleward with time? Fourth, what do these state-of-the-art climate models suggest about changes in the frequency vs. intensity of extreme Arctic cyclones?

APPROACH

I am targeting these objectives through a retrospective analysis of the transient 20th century simulations (spanning years 1850-2005) among the GCMs participating in the latest Coupled Model Intercomparison Project (CMIP5). I am including 14 GCMs with widely varying horizontal and vertical resolutions. These simulations are being compared with a new atmospheric reanalysis data set covering almost this entire period (1871-2008) from NOAA's Earth System Research Laboratory: the 20th Century Reanalysis, version 2, available at www.esrl.noaa.gov/psd/data/gridded/data.20thC_ReanV2. This data set is described in detail by Compo et al. (2010) and provides various atmospheric fields, including sea level pressure (SLP), on daily and sub-daily time scales at 2° horizontal resolution. A higher-resolution and more reliable data set for the more recent 1979- period, NASA's Modern Era Retrospective-analysis for Research and Applications (MERRA), is also being used to evaluate the climate models. All of this work is being conducted by the PI.

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WORK COMPLETED

I have mostly completed the 1850-2005 analysis of CCSM4, the primary GCM in this analysis, and its comparison with the 20th Century Reanalysis and MERRA. For assessing these changes during this period of modest greenhouse forcing, I have also made some comparisons with the model's response to much stronger greenhouse forcing during its 21st-century simulation. A more substantial portion of the project in the past year has been a retrospective, multi-model analysis of 14 GCMs in the CMIP5 data set over the 1850-2005 period. This work was presented at the Summer 2012 Community Earth System Modeling Workshop in Breckenridge, CO, and will be featured again at the upcoming 2012 AGU Fall Meeting ("Simulation of Extreme Arctic Cyclones in IPCC AR5 Experiments"). I am in the process of writing up the results for an article in Geophysical Research Letters. I also provided expert assessment of this summer's Arctic "megacyclone", which made international news as a possible expression of regional climate change and a contributor to the record low sea ice extent this month. http://earthobservatory.nasa.gov/IOTD/view.php?id=78808

RESULTS

1. CCSM4 generates a significant increase in the strength and frequency of extreme Arctic cyclones in its 21st century simulation (2005-2100), with a maximum signal during autumn (Vavrus et al., 2011).

2. However, this same model does not show a strengthening of the most extreme Arctic cyclones during the 1850-2005 period, nor a significant change in their frequency.

3. The 20th Century Reanalysis does indicate a strengthening of the most extreme Arctic cyclones during similar time period (1871-2008), but most of this change occurs before 1920, when the data quality is questionable. The same conclusion generally holds for the reanalyzed frequencies of extreme cyclones, but this data set suggests noticeably higher occurrences in the high Arctic (poleward of 70°N) during the past 25 years.

4. CCSM4 produces more extreme polar cyclones than the Reanalysis, consistent with its bias toward low sea level pressure in the Arctic during almost every month (de Boer et al., 2011).

5. The CCSM4 simulations show an interesting shift in the location of extreme Arctic cyclones as a function of greenhouse warming (Figure 1). By the late 21st century, the model indicates a shift in the path of these storms, such that they emanate into the central Arctic Ocean from their preferred track over the North Atlantic-Barents Sea. However, this change is not effected by the modest greenhouse warming between 1850-2000, when the sea ice margin is further south and may act as a barrier for the production or migration of such extreme events.

6. On the whole, the GCMs in the CMIP5 collection do a reasonable job of reproducing the location, frequency, and intensity of the strongest cyclones (top 1%) in the Arctic during the recent past (1979-2005). The favored regions for these storms are within the climatological Icelandic and Aleutian Lows, and extreme cyclones reaching the Arctic Ocean occur almost exclusively as extensions from the Icelandic Low storm track, rather than from the Aleutian Low track. Simulated and observed intense Arctic cyclones are primarily marine phenomena, such that maximum frequencies occur over water, especially ice-free seas.

7. The models also correctly simulate that the most intense Arctic cyclones are primarily a wintertime phenomenon and almost never occur during summer, but the CMIP5 models have a bias of producing too many such storms during the late winter and early spring.

8. The CMIP5 models simulate a decrease in mean annual Arctic sea level pressure since 1850, consistent with expectations from greenhouse forcing, but the trend in extreme cyclone frequency is most pronounced in the vicinity of the Aleutian and Icelandic Lows, rather than over the Arctic Ocean.

9. Over the Arctic, I find no significant correlation between horizontal or vertical model resolution and simulated annual-mean SLP, mean minimum daily SLP, absolute minimum SLP, and extreme cyclone frequency. Apparently, sea level pressure biases in the models and the simulation of intense storms are affected more by internal physical processes, rather than resolution.

IMPACTS

These results have implications for navigation, economic activities, military operations, and coastal erosion. Existing Naval operations in the Arctic Ocean and adjacent seas can be adversely affected by the passage of extreme cyclones, and future operations will likely become even more sensitive to these weather systems if reduced ice cover promotes more Naval activities and enhanced storminess in the region. A recent paper by Overeem et al. (2011) documents accelerating rates of coastal erosion in permafrost bluffs along the Beaufort Sea, due to storm-generated waves coinciding with expanding areas of open water. Presumably, this erosion will worsen with time as sea ice recedes and storms intensify.

RELATED PROJECTS

This topic is directly related to follow-up research I recently proposed to NSF in collaboration with scientists at the National Center for Atmospheric Research (NCAR), University of Colorado, and University of Oklahoma to investigate the predictability of Arctic climate on seasonal to decadal timescales. ["Arctic Atmosphere and Sea Ice Predictability and the Interrelation on Decadal and Sub-decadal Timescales", PIs: Steve Vavrus, Marika Holland, Jennifer Kay, Amy Solomon, Gijs de Boer, and Steven Caballa, submitted to NSF on May 10]

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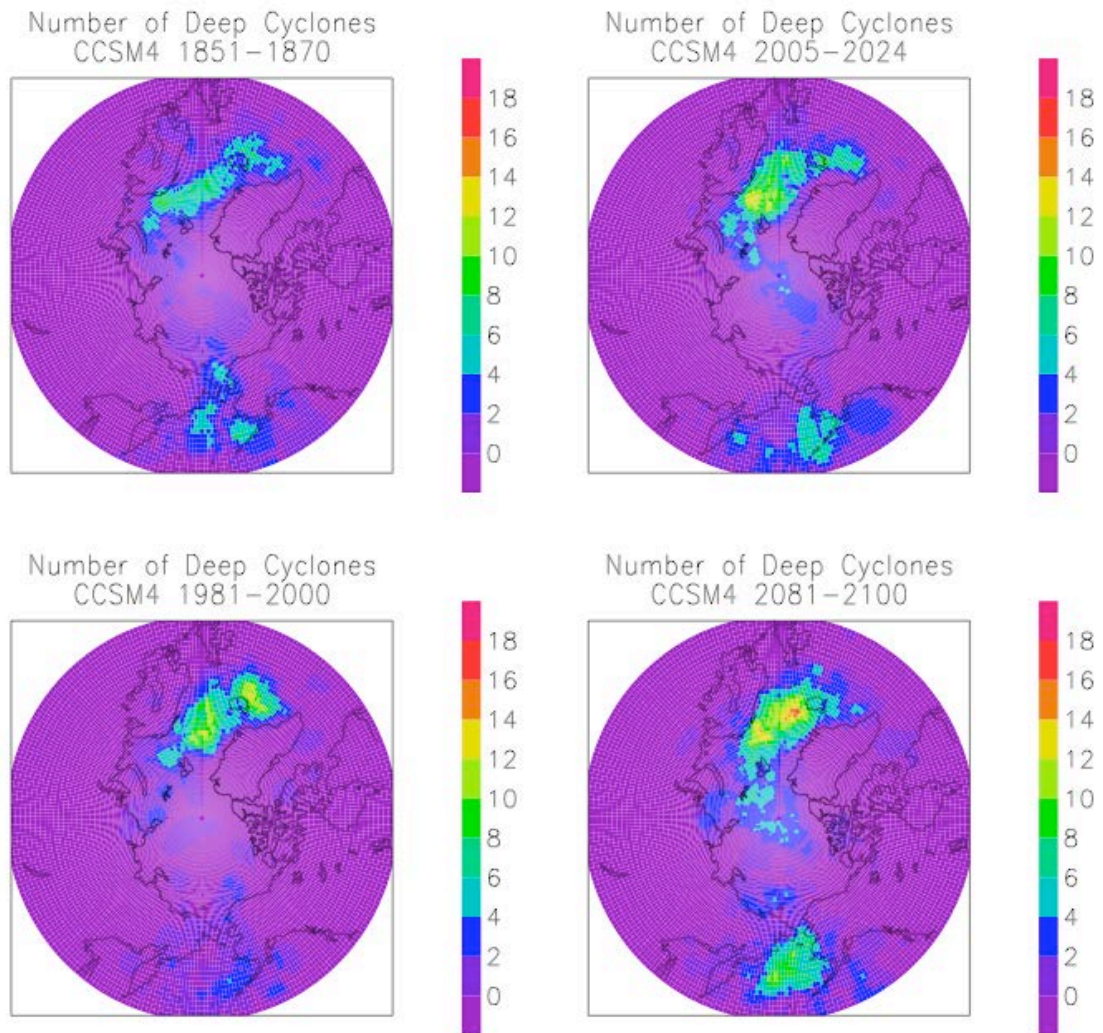
Figure 1. Changes in the simulated frequency (events per 20-year interval) of extreme Arctic cyclones (< 950 hPa) in the CCSM4 climate model during the middle 19th century, late 20th century, early 21st century, and late 21st century.

Intensity of Strongest 1% of Arctic Cyclones (1850-2005)

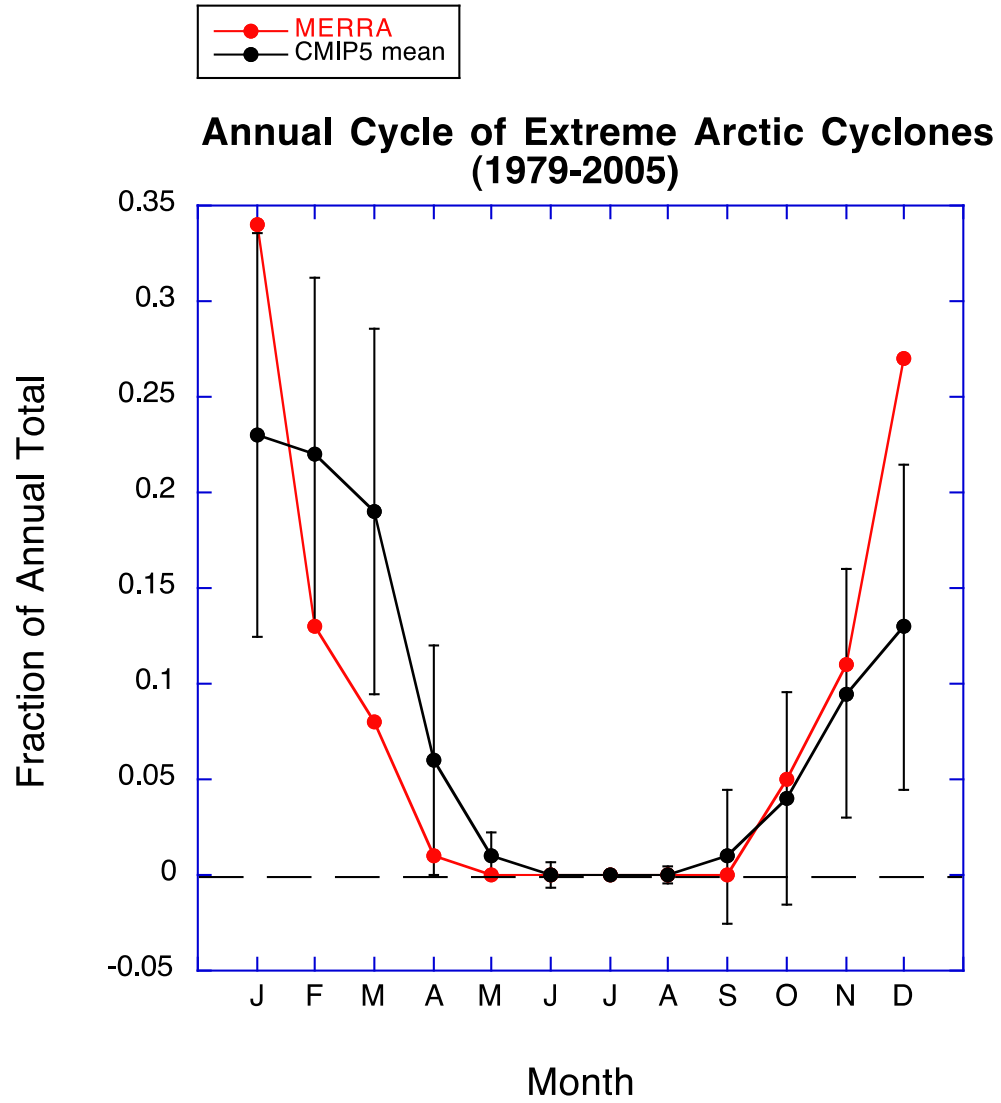CMIP5 mean: 960.5
MERRA mean: 958.3
(1979-2005)
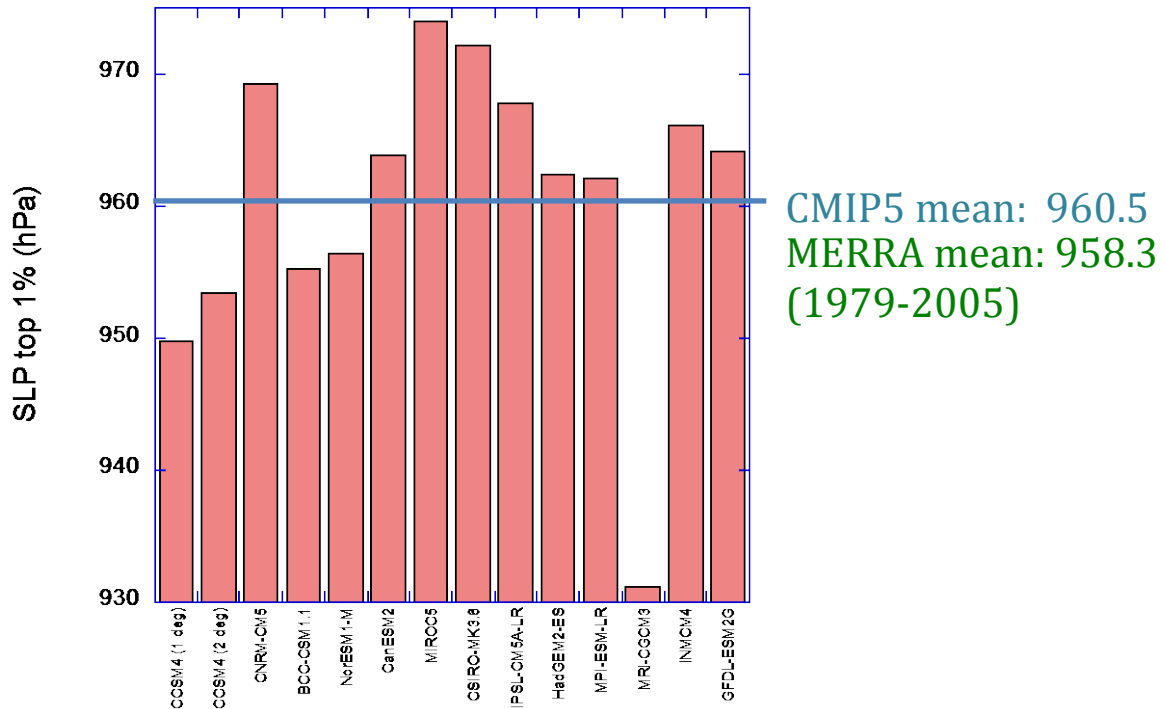
Figure 2. Simulated intensity (hPa) of the top percentile of Arctic cyclones in the CMIP5 models (1850-2005) compared with MERRA reanalysis (1979-2005).
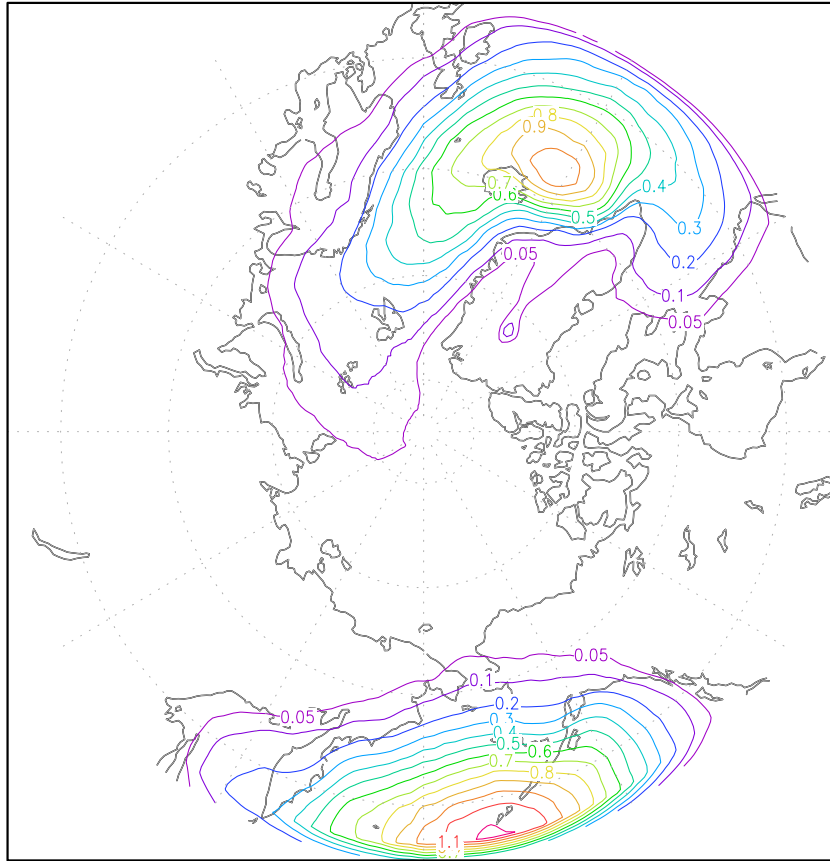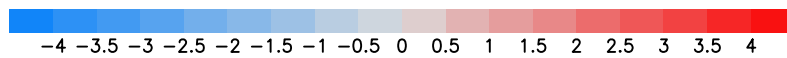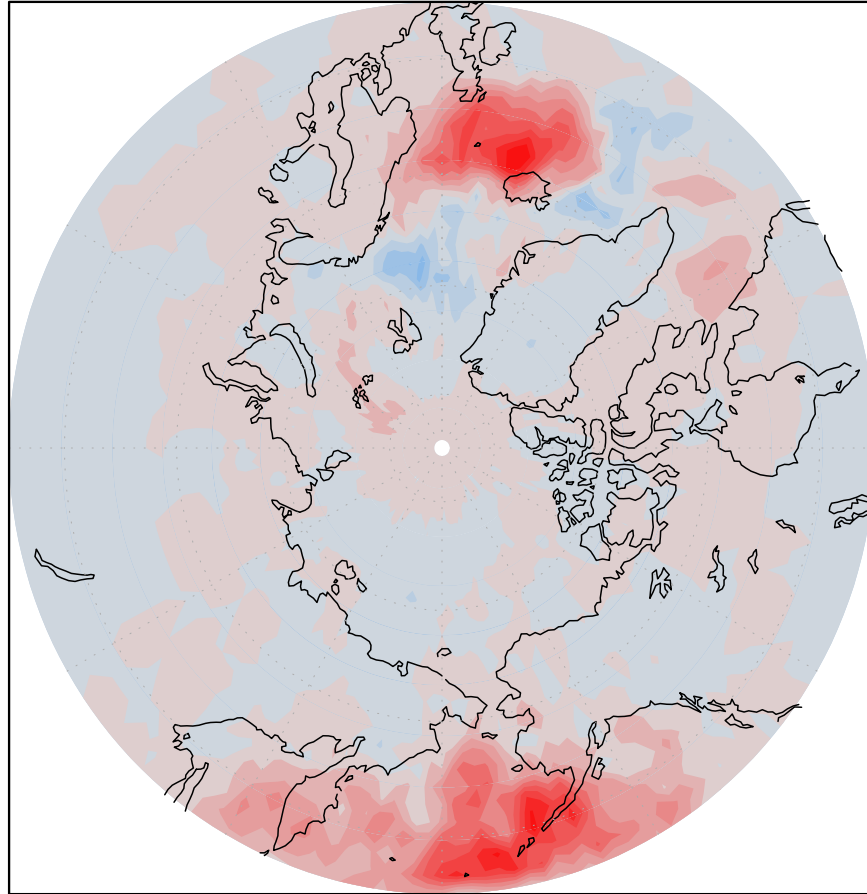
Figure 3. CMIP5-average annual frequency of extreme Arctic cyclones (deepest 1% of daily minimum SLP poleward of 50°N).

Figure 4. Annual cycle of extreme Arctic cyclones, as simulated by the CMIP5 models (black) and MERRA reanalysis (red).

Model Average Trend in Extreme Cyclone Frequency (x10E4) 1850−2005

Figure 5. Multi-model trend (x 10E4) among CMIP5 GCMs in extreme Arctic cyclone frequency between 1850-2005.